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Medical Natural Sciences: a new academic program to train biomedical researchers

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Abstract— Here we describe the academic program Medical Natural Sciences that was started as a bachelor program in 2001 by several departments of VU University Amsterdam and the VU University Medical Center in Amsterdam. In this program students receive training in exact sciences (physics, chemistry and mathematics) in a strong medical context, combined with basic courses in biomedical sciences and a program of general academic skills. The main goal is to provide the students the skills to conduct research in the fields of biomedical physics, medical physiology and clinical chemistry. The program fills a niche between more biologically oriented programs like Biomedical Sciences (with usually much less emphasis on physics and mathematics skills) and more technologically oriented programs like Biomedical Technology (with usually less emphasis on fundamental molecular aspects). The bachelor program was in 2004 followed by a master program, in the Netherlands required for entering a subsequent Ph.D. program. The combination of the MNS bachelor program and the MNS master program with specialization Medical Physics is acknowledged by the Dutch Society for Medical Physics as an allowed trajectory for the profession Clinical Physicist. Almost all graduated master students did easily find Ph.D. positions in university medical centers.

Keywords— Medical Natural Sciences, Education, Biomedical Physics, Clinical Chemistry, Clinical Physics, Medical Physiology, Molecular Diagnostics

I. INTRODUCTION

Modern biomedical research requires an integration of several academic disciplines. This has for many universities led to collaborations between science faculties and university medical centers, in particular in the domains of biology and medicine (Biomedical Sciences) or (bio)technology and medicine (Biomedical Technology). Combinations of exact sciences (physics and chemistry) with medical science are rare. In modern biomedical research and in medical practice, however, basic knowledge of principles of physics and chemistry are often indispensable. Physicians are increasingly using highly advanced techniques and require profound knowledge of the interaction of electromagnetic radiation and tissue to understand images obtained by, e.g., MRI, PET, photoacoustics, etc. There is also increased attention for molecular medical research, especially in view

of initiatives like translational medicine and the use of biomarkers for diagnostics.

These developments require academic professionals who received high-level training in physical, chemical and mathematical sciences applied to medical questions, on all levels between molecules and the complete human organism. The program Medical Natural Sciences (MNS), developed by the science department of VU University Amsterdam (VUA) and by several departments of the VU University Medical Center (VUmc), is meant to train bachelor and master students in the abovementioned aspects of modern biomedical research. In this paper, we will first explain the MNS bachelor program in more detail, and then briefly also explain the Medical Physics track of the MNS master program.

II. MNS BACHELOR PROGRAM

Overall scheme: In the bachelor program MNS (3 years, 180 ECTS) developed in Amsterdam the students receive theoretical and practical training in five different disciplines or fields: 1) physics and biomedical physics, 2) chemistry and molecular diagnostics, 3) mathematics and informatics, 4) medical sciences and 5) general academic skills. The sciences physics, chemistry and mathematics are taught in a medical context, and these five fields define MNS and distinguish it from other programs. In the first five semesters, the students follow courses in these fields, alternated by two one-month integrated projects in which these disciplines

Table 1 Organization of the MNS bachelor curriculum

Discipline or Field	ECTS	Semester
Physics and Medical Physics	42-45	1-5
Chemistry and Molecular Diagnostics	28-40	1-5
Mathematics and Bioinformatics	23-39	1-5
Medical Sciences	12	1-3
General Academic Skills	13	1-6
Integrated Projects	12	1,2,4
Bachelor Project and Thesis	12-24	6
Choice	18-30	3,5,6
Total	180	

come together. In the last semester the students prepare their bachelor thesis, based on a 2-4 month research project conducted in one of the research groups associated with MNS. In the remaining time, they follow courses meant for orientation on subsequent education or employment. Table 1 summarizes the topics of the MNS bachelor program.

Physics and Biomedical Physics: In modern biomedical research a deep level of theoretical and practical physics skills is indispensable. In MNS we train the students both basic physics skills as well as physics required for medical applications. The students follow theoretical courses in mechanics, electricity, magnetism, optics and quantum mechanics, and also follow practical training in the physics laboratory. In the latter not only experimental techniques, data acquisition and data analysis are trained, but also more general skills like defining research questions, making work plans, critical interpretation of results and oral and written presentation of results. We offer courses on biomedical physics (including biomechanics, fluid dynamics in blood, electric conductance in tissues, radiotherapy and the use of physical techniques in diagnostics), medical technology (from the physical principles of medical technology to the use in hospitals and quality, safety and legal issues) and advanced optical techniques (with explanations of optical instruments like microscopes and camera's and of the human eye, and of techniques like interferometry). In addition, many students take a combined theoretical and practical course on electronics and signal transduction as a free choice course.

We also offer a course focused on physical biology of the cell, in which the students gain insight in how tools and knowledge of physics and mathematics can be used to better understand biology on the molecular and cellular level and how quantitative models can be build to gain better knowledge of biological cells. In the part Life at Rest basic concepts of thermodynamics are covered, which are thus explained in a biological context, while in the part Life in Motion concepts like biological dynamics, rate equations and dynamics within the cell, statistical thermodynamics and biological electricity are covered.

Chemistry and Molecular Diagnostics: Modern biomedical research requires a deep understanding of molecular processes in the human body, and therefore requires understanding of its chemistry. In MNS the students learn the chemistry that is needed for their development as biomedical professionals. The students obtain basic knowledge in the fields of biochemistry, physical chemistry, (bio)analytical chemistry, clinical chemistry, structural biology, and chemical thermodynamics. With these courses the students obtain insight in the chemical constituents of living cells, the molecular biology of the living cell, genetics and DNA technology, bioenergetics, bio-analytical tech-

niques like chromatography, electrophoresis, mass spectrometry and reaction-detection systems, NMR spectrometry, electron crystallography and various types of microscopy, while they also learn how to use biomarkers as tools for clinical diagnostics. In the chemistry laboratory the students receive hands-on training in (bio)chemical techniques applied on experiments focused on pharmacology, toxicology or clinical chemistry.

Mathematics and (Bio)informatics: MNS students are expected to be able to use mathematics tools for data analysis and modeling. The students are trained in basic mathematic skills including calculus, vectorcalculus and linear algebra, and also learn to work with Fourier transformations and partial differential equations. Some students take more advanced mathematics courses in their free choice program. Also mathematical statistics and data analysis form part of the program, as well as an introduction to bioinformatics and statistical methods used for bioinformatics research. The students also get an applied informatics course in which basic concepts of informatics are combined with biomedical applications.

Medical Sciences: In order to familiarize the MNS students with the functioning of the human body, they get courses focused on medical physiology and pathology. By means of lectures, patient demonstrations, case studies, working groups and practical training the students learn basic physiological aspects of organs in health and disease.

General Academic Skills: It is important that students realize that in order to become a good scientist or biomedical professional, more is needed than to gain knowledge, insight and practical skills in exact and medical sciences. Special attention is therefore paid to philosophy of science, societal and historical aspects of science, ethics and societal aspects related to medical research, career perspectives and general skills like oral and written presentation.

Integrated Projects and Bachelor Thesis: At two points in time in the curriculum integrated projects are offered in which small groups of MNS students combine several disciplines and skills to carry out a project. The first project is focused on nerves and includes a case-study in the hospital environment of neurophysiological diagnostics, and the modeling and simulation of action potentials and electric responses. The second project deals with cancer, including lectures on the molecular basis of cancer, demonstrations of radiotherapy and chemotherapy, and practical training involving molecular biological research on model systems.

In the last semester the students carry out an individual research project of two months in one of the departments of VUA or VUmc. The students can use a part of their optional program to extend this project to maximally 4 months. The project is completed by a written bachelor thesis and an oral

presentation of the results. A few representative titles of completed MNS bachelor theses:

- Confocal microscopy of stem cells in collagen
- Absolute dosimetry
- Localization of brain activity using fMRI
- Mechanosensitivity of osteocytes
- Motor activity of kinesin
- Yeast model for determining the role of α -synuclein in Parkinson's disease
- The GroEL molecular chaperone system and bacteriophage T4gp31

After completion of the MNS bachelor program the students are in theory able to find a position in the public or private sector for which academic attitude and level is required. It is also possible, after a 6-month education training, to become teacher in physics or chemistry in the lower levels of Dutch high schools. Most students, however, opt for a subsequent master program. Because of the broad and fundamental nature of the MNS bachelor program, there are many master programs in Amsterdam, the Netherlands and Europe in which MNS students can enroll without having to pursue a premaster program. These programs include masters, apart from MNS, in Neurosciences, Oncology, Systems Biology, Bioinformatics and Cardiovascular Research.

III. MNS MASTER PROGRAM

The MNS bachelor program is followed by a 2-year MNS master program (120 ECTS). The program is entirely in English and is therefore also accessible for students from abroad. All students and teaching staff are required to show that they have sufficient English language skills to enter the program or to teach. In this sense this program does not differ from most other master programs in the Netherlands.

The MNS master program is a multifaceted program that combines physics and chemistry with medicine, and is therefore also called Science in Medicine. This combination will introduce the students to innovative ways of conducting medical research. In the MNS master program we distinguish four different programs or tracks (see Table 2). The Medical Physics and Physics of Life tracks share an orientation on physics, with the main difference being that Medical Physics focuses on cellular and higher levels and medical topics, and that Physics of Life focuses on fundamental molecular levels and life in general. The Medical Physics track is explained in more detail in the following.

Table 2 Master tracks of the MNS master (VUmc = VU University Medical Center, VU = VU University Amsterdam)

Discipline or Field	Offered by
Medical Physics	VUmc + VU
Medical Physiology	VUmc
Molecular Clinical Diagnostics	VU + VUmc
Physics of Life	VU

MNS track Medical Physics: Thus far, this track attracted more than half of all MNS master students. It was initially offered by the Department of Physics and Medical Technology of VUmc, but with the appointment of a new chair Biomedical Photonics in February 2008 at VUA, Medical Physics became a joint VUmc-VUA track.

Table 3 shows the general scheme of the MNS master. It starts with 4 compulsory courses of 6 ECTS each, i.e., Physics of Life (which covers the physics of the interaction between the different types of radiation – electromagnetic, radioactive and ultrasound – with tissues of the human body, and of image formation in medicine), Modeling and Simulation in Medical Sciences, Soft Condensed Matter and Biological Physics and Mechanics of Tissues. With these courses the students obtain the fundamental physical knowledge to conduct high-level research in biomedical physics. The students also follow general courses on ethics and scientific writing in English. After that, an individual program is followed in which the students perform two research projects, a literature survey and an optional program, which they can use for advanced theoretical courses (examples: Techniques in Molecular Biophysics and Parameter Estimation in Brain Imaging), or an extension of one of the research projects. The students can do their research projects not only in Amsterdam, but also in nearby Academic Medical Centers (Amsterdam, Leiden or Utrecht) or elsewhere in the world, provided that a member of the senior scientific staff of VUA or VUmc serves as second reviewer. The research projects in Amsterdam are focused on cardio-, circulatory and pulmonary physics, brain imaging and neurophysics, skeletal physics and tissue engineering, clinical physics and advanced optical and microscopic techniques for diagnostics and treatment of patients (like Optical Coherence Tomography). The latter projects are carried out in the Amsterdam Institute for Laser Science and Biophotonics.

Table 3 Organization of the MNS master curriculum

Discipline or Field	ECTS	Semester
Compulsory courses	24	1
General courses	6	1
Literature thesis and colloquium	12	2-4
Minor program	21	2-4
Research project	39	2-4
Optional program	18	2-4
Total	120	

IV. CONCLUSIONS

One of the main reasons to start the MNS bachelor and master program is to attract students with interest in medical topics and skills in exact sciences, but with no immediate desire to become trained as a doctor or to start a program with a very strong emphasis on technology. In this sense the program fills a niche between programs like Biomedical Sciences (which at least in Amsterdam is focused on the understanding of the functioning of the human body, and for which hardly mathematics and physics skills are required to complete this program) and Biomedical Technology (which is usually more focused on technology and less on fundamental physics and chemistry). The bachelor program runs for seven years, and the program is now one of the largest programs within the Faculty of Sciences (which offers a total of 11 bachelor programs in the fields covered by chemistry, physics, mathematics and informatics). One of the reasons for its success is that university, medical school and hospital are located within walking distance on the same campus. About half of the students is female, which (in Amsterdam and the Netherlands) contrasts the very low

percentage of female students in the traditional monodisciplines physics and chemistry. So we feel that a new population of students is attracted that potentially can become medical physicists and that otherwise would have been lost for a career in biomedical physics, because of Physics or Biomedical Technology do in their view not appeal enough to their wishes and the for them more appealing alternative Biomedical Sciences does not include sufficient mathematics and physics to become a medical physicist.

Since a few years the combination of the MNS bachelor program and the MNS master program with specialization Medical Physics is acknowledged by the Dutch Society for Medical Physics as an allowed trajectory for the profession Clinical Physicist. In the Netherlands, MNS is the only program next to Physics at a general university that is acknowledged by this society.

MNS bachelor students can choose between many different master programs and thus have many possibilities to pursue their education. We feel that this is because of the educational concept of MNS, which focuses on skills (both theoretical and practical) rather than knowledge. Nevertheless, many MNS bachelors pursue their training with the MNS master program with specialization in medical physics. Almost all MNS-medical physics masters could easily find subsequent employment and/or a Ph.D. program in a university medical Center and are currently involved in high-level biomedical physics research.

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